(12) EUROPEAN PATENT APPLICATION

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(54) An automated chemical milling process.

(57) The specification discloses an automated chemical milling process for metal articles. The metal article is first coated with an etchant resist coating. In one embodiment, the area to be etched is digitized to define the x, y coordinate values for the perimeter line around the area. A CPU is used to control a flatbed drafting table with a tangentially controlled scribing tool to cut through the resist coating along the perimeter line. If plural etching steps are used, each perimeter line is digitized and scribed or cut in a similar manner. All but one of the perimeter lines are recoated and marked, and the resist coating within the remaining perimeter line is removed. The metal part is then etched as desired. If plural etching steps are used, the resist coating for each separate area is removed between sequential etching baths. In a second embodiment, the x, y, z point coordinate values for a perimeter line one a three-dimensional workpiece are defined, and the scribing operation is done by a robotic device controlled by a CPU. In a third embodiment, new template or mask geometry is created on a CRT and digitized for subsequent control of the plotting table or other robotic device. Digital signals are used to define the x, y or x, y, z point coordinate values while analog signals are used to control the scribing tool.

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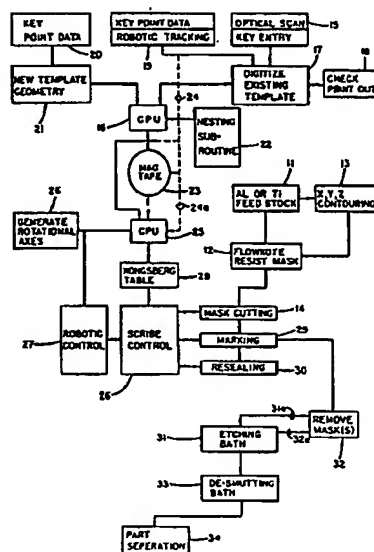
1 <u>AN AUTOMATED CHEMICAL MILLING PROCESS</u>

The field of the present invention relates to an improved automated method for chemically milling metal and
5 metallic structures. Chemical milling is widely employed in the aircraft and aerospace industries to remove excess metal from metal parts wherein the removed metal is not essential to the strength of the component part. The chemical milling process normally employs a series of masking and metal removal
10 steps. The metal is removed by an etching bath which may be either caustic or acid depending upon the metal or alloy being etched. Chemical milling may be used to produce one piece structures having a skin and load bearing ribs or stiffeners that provide lightweight alternatives for traditional aircraft
15 skin and stringer constructions.

The prior art has used chemical milling to reduce the weight of metal parts intended for use in aircraft or aeronautic applications for over twenty years. Chemical milling is widely used to increase the strength to weight
20 ratio of component parts in the aircraft airframe. Chemical milling traditionally involves the steps of masking and chemically milling a metallic workpiece and may repeat the sequence several times to further alter the workpiece configuration.

25 U.S. Patent 4,137,118 discloses a method of chemically etching an efficient lightweight structure by removing excess metal to form the ribs and skin of an aircraft structure. The etching step is repeated to sequentially undercut and impart an "I" or "T" section to the ribs and to
30 reduce the thickness of the skin.

U.S. Patent 3,745,079 discloses a method of chemically etching a titanium alloy stock for use as a structural member in an aircraft.

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1   U.S. Patent 2,888,335 discloses a process of chemically etching a workpiece that sets forth a method of sequentially etching the workpiece with multiple cuts in the mask material to produce a plurality of etched levels in the
5   workpiece. In between each etching bath, a portion of the mask is removed so that the final configuration has an etch pattern of varying depths throughout the workpiece.

U.S. Patent 3,380,863 discloses masking material for use in chemical etching having a styrene/butadiene block
10   copolymer composition. This material is widely used in chemical milling processes for masking the part to be protected during the etching bath.

At the present time, the prior art methods comprise the steps of marking the aluminum or titanium stock with a
15   reference mark or tooling hole for conveying the stock through the etching solution. The metal part is then covered or coated with the butadiene/styrene copolymer masking material. A template is laid over the masking material and the masked material is handcut along the template line. The masking
20   material is then marked with a marking pen along the cut or scribe line. These steps are repeated with separate masks when separate etching or milling levels are contemplated. In the event multiple etching baths are desired, the cut mask line is recovered with a sealant material. After all of the
25   stencil marks have been cut, and the secondary cuts have been coated, one portion of the mask material is removed. The metal plate is then etched and rinsed in a counterflow rinse water. The second mask area is removed, and the workpiece is reimmersed in the etching bath. The workpiece is rinsed again
30   and the process is repeated for the desired number of etching steps. At the conclusion of the etching step, the workpiece is "de-smutting." A typical "de-smutting" agent is disclosed in U.S. Patent 3,988,254.

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1   There are two problems in the present prior art method of chemical milling that are solved by the present invention.

       a) controlling the depth of the cut through the
5 masking material. At present, the mask is handscribed by. skilled workmen. If the cut is too deep, the cut allows the etching bath to etch into the metal and undercut the mask. If the cut is too shallow, and the mask material is not completely severed, it will "blowout," blister or tear when
10 that portion of the mask is removed. This necessitates a time-consuming repair step for the stencil mask. In addition, if the "blowout" is not detected, the workpiece will be undercut by the etching material.

       b) the time consumed in laying each stencil on the
15 workpiece, marking each line to be cut and cutting each line by hand is substantial. A typical three-feet by four-feet workpiece requires six to eight hours of hand labor to handmark and cut each of the areas to be etched. The automated process of the present invention can do the same
20 marking and cutting in 11 minutes. In addition, it can perform cuts that cannot be done by hand.

       If the chemical milling is done on a three-dimensional workpiece, all of the foregoing problems are accentuated. In addition, it is necessary to preform the
25 metal part around a master mold in a molding or die-stamping step to provide the desired three-dimensional configuration. Each of the stencils must be provided with the appropriate compensation for three-dimensional positioning. In the present prior art practice, after the metal plates have been
30 preformed to an approximate three-dimensional configuration, they are pinned to a master mold, and the individual stencils are also pinned to provide intimate contact between the

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1 stencil and the workpiece. Further, the three-dimensional nature of the workpiece makes it even more difficult to accurately handcut the stencil to the desired depth.

The present invention involves the new use of two
5 existing devices which have heretofore been used for other tasks.

In the drafting and cartography fields, large computer operated drafting machines have been used to mark blueprints and scribe plastic stencils that are intended for
10 use in photoreproduction processes. These machines are quite large, having a drafting area that may be 8 feet wide by 34 feet long. A motorized carriage traverses the drafting bed in both the x and y dimensions and carries on its carriage a plurality of marking pens. One such device is the Kongsberg
15 1800S Series Flatbed Drafting Table. This drafting table may be fitted with a variety of drafting tools including a tangentially controlled scribing tool. This tool uses a single knife or chisel and is normally used for cutting and stripping material used in the photoreproduction of integrated
20 circuits. The knives are used to scribe coated films.

U.S. Patent 3,555,950 discloses a device for automatically cutting a photomask for use in producing integrated circuits. In this device, the aluminum foil is cut, and the plastic laminate material is retained to define
25 an optically transparent negative for producing an integrated circuit board.

Computer controlled cutting means have been widely used in the garment industry for cutting one or more sheets of fabric to a desired pattern size. These devices also have
30 drive motors for moving a cutting tool in x and y directions. Examples of computer operated cutting devices are disclosed in U.S. Patents 3,803,960, 3,805,650, 3,895,358, 3,991,636 and 4,171,657.

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1   While the foregoing devices have been used for
computer controlled cutting of cloth and photomasks in the
prior art, they have not been used or applied to the chemical
milling process. The chemical milling process has remained
5 essentially unchanged for over 20 years. The computer
controlled flatbed drafting tables and cutting tables have
been in existence for over 10 years. To the best of
applicants' knowledge, these devices have not been used in the
chemical milling process, and their use in this field provides
10 significant advantages in both speed and accuracy.

The foregoing devices, while suitable for
application to chemical milling involving flat stock, are not
suitable for use in chemical milling processes on
three-dimensional workpieces. For three-dimensional milling,
15 the tangentially controlled scribing tool is mounted on a
robotic device that may be computer controlled through the
x, y, z dimensions to provide an accurate scribing depth as the
robotic device traverses the three-dimensional contoured
surface. One robotic device that may be modified for use in
20 the chemical milling process is manufactured by ASEA, Inc. and
is described in the ASEA pamphlet YB 11-101 E.

Both the ASEA robotic device, and the Kongsberg
Drafting Table are capable of traversing an existing template
to derive a series of point-by-point measurements along the
25 perimeter defined by the template. These point-by-point
measurements may be recorded and stored on magnetic tape.
These point-by-point measurements may then be used to scribe
the mask covered workpiece with the tangentially controlled
scribing tool carried by the Kongsberg plotter or the ASEA
30 robot.

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1   An alternate means of generating the instructions
for controlling the movements of the robotic device or the
flatbed drafting device is to create new template geometry on
a CRT via an existing computer program that is currently sold
5 under the "CADAM" tradename. This program will define the x
and y coordinate values of the newly created mask before they
are digitized and stored on magnetic tape.

        The present invention relates to an automated
chemical milling process for metals, said process comprising
10 coating the metal to be etched with a resist coating,
digitizing the area(s) to be etched to define at least x and y
coordinate values for the perimeter of the area(s) to be
etched, automatically scribing the metal and coating with a
scribing tool, said scribing tool cutting through said coating
15 along the perimeter defined by the x and y coordinate values,
removing the resist coating from the area(s) to be etched and
immersing said partially coated metal into an etching solution
for a predetermined period of time to remove a predetermined
amount of metal from the uncoated area(s). It includes
20 digital automation and the application of two separate and
existing devices to a field of use in which they have not been
previously used. The present invention includes the steps of
coating the metal that is to be milled or etched with an
etchant resistant mask, such as a styrene copolymer. The
25 perimeter of the area to be etched is then digitized to define
a plurality of point definitions along the x,y axis of the
flat metal stock, or through a set of x,y,z axes for
three-dimensional workpieces. If more than one area is to be
etched in a sequential etching process, the values of all of
30 the coordinates are defined and stored on a magnetic storage
medium such as a magnetic tape, a disc drive or a bubble
memory means.

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1　　　　　　Figure 5 is a curve illustrating the depth of the
cut made by the tangentially controlled scribing device in
response to various "force settings."

　　　　　　Figure 6 is a perspective view of the carriage
5 assembly that carries the tangentially controlled scribing
device, the markers and the recoating device for sealing
previously scribed cuts.

　　　　　　Figure 7 is a perspective view of the Kongsberg
Flatbed Drafting Table.

10　　　　　　Figure 8 is a diagramatic view of the ASEA robotic
device and a three dimensional workpiece.

　　　　　　Figure 9 is a diagramatic illustration of x,y,z and
Y coordinate axes.

　　　　　　Figure 10 is a partially cross sectional and
15 perspective view of a portion of a three-dimensional workpiece
formed by the present invention.

　　　　　　Figure 11 is a perspective view illustrating the
registration or tooling holes that may be formed by the
present invention.

20　　　　　　Referring to Figure 1, the automated chemical
milling process of the present invention is set forth in a
diagramatic flow chart. The aluminum alloy or titanium alloy
feed stock 11 is first cut to size for the part to be
produced, or a series of parts when a plurality of parts are
25 intended to be produced from a single piece of feed stock. If
the feed stock is a flat stock, it then proceeds to the flow
coating process 12 wherein it is flow coated with the styrene/
butadiene copolymer resist mask sold under the tradename of
"Turco Mask 522." "Turco" is currently available from Turco
30 Products, Inc., Wilmington, California. If the feed stock is
intended for use as a three-dimensional workpiece and is not
provided as a three-dimensional feed stock, it then proceeds

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1 to a contouring or stamping step 13 wherein the flat feed
stock is contoured to the desired three-dimensional
configuration.

After the feed stock has been coated with the
5 styrene/butadiene copolymer, it then proceeds to the mask
cutting step 14.. As was indicated previously in the prior
art, the mask cutting was accomplished by laying a template
over the feed stock and marking the outline of the template on
the feed stock. The marked outline is then handcut so as to
10 cut through the resist coating and lightly score the surface
of the metal workpiece. The desired depth of cut into the
metal workpiece is .001 inches. Current military
specifications for use in aircraft intended for purchase by
the United States Government proscribe a maximum cut into the
15 workpiece of .004 inches. If the cut is too deep, the
subsequent etching step will undercut the resist coating, and
if the cut is not deep enough, it will cause a "blow-out" when
the center portion of the template is removed for etching.
The "blow-out" must then be retouched by hand, which is a time
20 consuming, labor intensive operation.

The present invention automates the chemical milling
process by one of three separate beginning steps. As
indicated at 15, an existing template may be placed on top of
the workpiece, and an optical scan made of the template. All
25 of the initial starting marks, the workpiece size, the
template number and other desired information is keyed into
memory along with the optical scan to provide the data
necessary to align the cutting device at the appropriate point
on the workpiece when the mask cutting operation 14 begins.
30 In lieu of using an optical scanning device, a stylus may be
used to trace the outline of the template while each of the
reference points along the template are keyed into memory via

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1 the CRT. For a simple, flat two-dimensional workpiece, each
of the straight lines could be keyed by placing the stencil at
the corner and keying in the positional data and cut
orientation. The stencil would then be moved to the end of
5 that particular straight line and the second key point set of
data would be entered. These steps would be repeated around
the entire perimeter of the template until the desired area to
be etched had been completely defined by the reference point
data.

10   .   In the event the workpiece was intended in a
sequential or multiple etching process, the next template
describing the second area to be etched would then be overlaid
with respect to the initial·reference marks, and it would be
optically scanned, or traced with a stylus pencil to derive
15 the key point data for the existing template.

Simultaneously with the optical scan and the initial
key data steps, the CPU 16 would be digitizing the x,y
coordinate values of each of the key points entered at 15.
The digitizing step is indicated as a separate step 17 in
20 Figure 1 inasmuch as a variety of methods for digitizing an
existing template exist. Two methods for digitizing an
existing template were set forth above, but is apparent to one
skilled in the data processing art that a variety of methods
could be used to define the x,y coordinate values and convert
25 them to digital form for use in a conventional CPU 16.

After the template has been converted to digital
form,. a printout is produced as indicated at 18. This
printout may be done with a Kongsberg flatbed drafting table
similar to the one that will be used with respect to the mask
30 cutting operation 14 later on in the process. The Kongsberg
flatbed drafting table currently available from "Kongsberg
North America, Inc.," 135 Fort Lee Road, Leonia, New Jersey
07605. Any printout device will work providing it is capable

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1 of generating a full size template that may be physically
checked against the template that was entered via the optical
scan or key data entry indicated at 15.

The entry of the x,y,z coordinate values for the
5 robotic device is similar to that used for the digitizing of
existing templates for flat feed stock.

As was indicated previously, it is customary to
initially preform flat feed stock into its desired
three-dimensional configuration as indicated at 13. The
10 preformed flat stock is then placed onto a master mold which is
very precisely contoured with respect to the desired final
configuration. A three-dimensional template is then placed
over the feed stock and the resist coating is then cut.

As indicated above, the handcutting of the
15 three-dimensional workpiece is even more difficult and time
consuming than the cutting of a two-dimensional workpiece. A
constant pressure must be exerted to precisely track the
contours of the workpiece to completely cut through the mask
and lightly score the metal surface without causing any
20 undercuts or blow-outs.

In digitizing an existing template for the robotic
device, a similar process is followed. The "ASEA" robot is
equipped with its own computer guidance system and is normally
programmed by the "teach" method which uses a robotic tracking
25 method of tracing the stencil with a stylus to "teach" the
robot the desired contour to be followed. The "ASEA" robot is
currently available from "ASEA, Inc.", 4 New King Street,
White Plains, New York 10604. The stencil attached to the
robot is placed manually at the initial reference starting
30 position, and that key point data is entered. This operation
"teaches" the robot that this position is to be assumed with
respect to programmed operation for all future beginning
reference

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1 points. The digital positioning values for all three axes and
the required traverse speeds are then stored in the computer
memory. The robot is then moved manually along the template
to the next position and the second set of x,y,z coordinate
5 values is entered. The second set is then stored in memory,
and these steps are completed until the perimeter. of the
template has been completely traversed by the stencil. For
long straight cuts along a two-dimensional plane, only two
entry points need be entered. Along a complex curve or a
10 three-dimensional curve traversing all three x,y,z axes, each
coordinate value requiring a shift in the rotationals axes of
the robot needs to be entered. Once the entire outline of the
three-dimensional template has been entered into the robotic
memory, it can then be transferred to a magnetic storage
15 medium such as magnetic tape or a disc drive.

The reference point data is used as a simple way of
obtaining coordinate transformation in straight line
positioning for the robot. The reference point entered by the
key point data at 19 does not cause any robotic motion, it
20 simply defines the first, second, third...n, points of the
pattern of movement to be traversed. The distance and
direction to the subsequent reference point is calculated
between reference points and executed relative to the point in
space at which the robot is situated before the next reference
25 point is entered.

The ASEA robot will work in one of two modes. If
point-to-point control is selected, each of the several axes
that have to move simultaneously to reach a new point begins
at once, and the trajectory is not controlled. All axes will
30 start at the same position, and each motor will stop when its
driven portion has reached its new programmed position.

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1   The robotic device is also equipped with a separate
instruction function wherein the motor speed for each axes is
selected so that all axes reach the new position
simultaneously. This is particularly useful in following
5 contours generated by a series of closely related key data
points along a complex x,y,z coordinate curve.

        As indicated by the dotted line 24, the keypoint
data from the robotic tracking of the existing template can be
read out onto magnetic tape as indicated at 23 or any other
10 form of permanent magnetic storage media. When it is desired
to institute a production run, the magnetic tape created for
the part that is to be produced is read back into the robotic
memory for execution of the three-dimensional template.

        A third method of generating masks for the automated
15 chemical milling process of the present invention is
illustrated at 20 and 21 wherein new mask geometry is created
on a CRT through the use of a program entitled "CADAM." The
CADAM program is a commercially available, licensed software
program available through CADAM, Inc. in Burbank, California,
20 or from IBM.

        In using the CADAM program, the part to be created
is displayed on the CRT and a series of key points are entered
along the part to define the new mask geometry. The key
points are then filled in by the operator at the CRT to
25 completely enclose the perimeter of the new template geometry.
If sequential etching baths are desired, each of the templates
are generated by the operator at the CRT by entering the
desired key points to define the x,y values of each of the
points along the perimeter. The new template geometry is
30 digitized as it is created by the CPU 16, and, if desired, a
printout may be generated at indicated at 18 to check the mask
geometry against the feed stock example or an initial mock up
of the part that may have been created in the model shop.

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1   If the process involves the creation of a number of parts from a single piece of feed stock, a separate nesting subroutine 22 is used to nest the various template perimeters in the most efficient manner for the particular size and

5 configuration of the beginning feed stock. The "nesting" subroutine indicated at 22 is a software program entitled "CAMSCO" and is available through CAMSCO, Inc., 1200 N. Bowser, Richardson, Texas 75081.

        The digitizing of the existing template as indicated

10 at 17, or the creation if the new template geometry as indicated at 21, is stored in magnetic form in either temporary or permanent storage media as it is created. If it has been stored in a temporary memory, it is then converted to magnetic tape or disc as indicated at 23 for future use in the

15 manufacturing method. Inasmuch as a large aircraft manufacturer may have thousands of templates used for chemical milling parts for the aircraft, it is desired to have a permanent magnetic record as indicated at 23. This record may be used whenever it is desired to begin a production run for a

20 particular part or series of parts.

        As illustrated in Figure 1, a separate CPU 25 has been illustrated for use in the production line environment. In applicants device, CPU 16 is a computer that is normally used in the design and engineering departments while CPU 25 is

25 a separate computer that is used to operate the Kongsberg Flatbed Drafting Table. It would be possible, however, to use the same computer for both functions if desired. The ASEA robot has an integral CPU which may be used on line with CPU 25, or substituted therefor, if the template geometry has been

30 generated through the "teach" function.

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1   Instructions from CPU 25 to scribe control 26 utilizes only the x and y axes for flat feed stock. In the Kongsberg Flatbed Drafting Table, one motor is used for the x axis and one motor is used for the y axis. These are the only 5 two values that are digitized and used to control the positioning of the scribing tool. The scribing tool is controlled by an analog signal generated by the scribe control 26, as will be hereinafter described in detail.

When the process is used on three-dimensional 10 workpieces, the generation of the commands for the scribe control is substantially more complex. As indicated by the dotted line 24a, the magnetic tape 23 created by the robotic device during the "teach" function may be reinserted into the CPU controlling the robotic device, and each of the rotational 15 motions will be generated in the same sequence and order as they were "taught" to the device during the key point data step 19.

The robotic device contains three to six motors for traversing the x,y,z axes whereas the flatbed plotter uses two 20 motors for traversing the x,y axes. New three-dimensional templates may be created via a "CATIA" program as indicated at 21 for new template geometry. CATIA was developed by Dassault in France as a modification to the previously described CADAM program. CATIA is currently available from IBM. A separate 25 set of rotational commands must also be generated as indicated at 26 for each of the motors in the robotic device. This step computes the direction and speed of each of the motors necessary to traverse the x,y,z contour defined by the digitized x,y,z values at 21. This may be done as a separate 30 routine between the CPU and the robotic control, or it may be generated at the time the new template geometry is created by the CPU 16.

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1   The robotic control indicated at 27 is the process
of controlling the relative rotational axes of each of the
motors in the robotic device.

        As is apparent from Figure 1, the scribe controls
5   indicated at 26 may be derived in the three-dimensional
operating mode from the robotic control 27, or in the
two-dimensional mode from the Kongsberg table 28.

        Scribe control 26 is capable of effecting three
separate operations on each of the pieces of feed stock 11
10 that are flow coated as indicated at 12. These three steps
are the mask cutting indicated at 14, the marking step 29 and
the resealing step indicated at 30.

        If a simple one-step etching process is utilized,
the CPU 25 will drive the x,y motors of the Kongsberg table as
15 indicated at 28, while the scribe control 26 regulates the
pressure of the cutting knife and the orientation of the
cutting blade during the mask cutting operation 14. Since the
most is somewhat resilient, it is difficult to see the cut
lines in the mask. Therefore, after the mask has been cut, it
20 is conventional practice to mark the scribe line as indicated
by 29 with a marker to assist the workmen who remove parts of
the mask in finding the area to be removed. Inasmuch as
several thousand types of workpieces may come through the
production line for the etching bath 31, each with its own
25 particular configuration, and each with a separate number of
templates scribed thereon, the marking step, while not
absolutely essential, it is highly desirable to achieve
error-free etching or chemical milling.

        If multiple etching baths are desired for the
30 workpiece 11, the scribe control 26 then recoats all but one
of the template lines cut during the mask cutting operation
14. Normally, the innermost template is then removed as

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1 indicated at 32, and the workpiece is then immersed in the
etching bath 31. If multiple masks and multiple etching steps
are involved, the workpiece is recycled as indicated at 32a
for the removal of the second mask and a return to the etching
5 bath along 31a. After each of the areas have been etched on
the workpiece, it is then de-smutted in a de-smutting bath 33
and sent to a router for part separation as indicated at 34.
The part separation step 34 may be used when a plurality of
parts are nested on a single piece of feed stock, or when a
10 portion of the feed stock is used for the positioning of the
reference or alignment holes that guide the workpiece through
the various manufacturing steps that it will encounter.

As illustrated in diagramatic form in Figure 2, the
tangentially controlled scribing tool uses a single knife 35
15 that is secured in a central barrel 36 by means of a set screw
37. Barrel 36 is provided for both rotational and
reciprocating movement by means of an air bearing 37 which
completely surrounds torque piston 38. The piston 38 is
responsive to two orthogonal stator windings 39 and 40 which
20 are in turn connected to sine 41 and cosine 42 analog voltages
received from the scribe control 26 illustrated in Figure 1.
These voltages turn the torque receiver piston 38, and
subsequently the knife's leading edge to ensure that knife 35
always presents its normal cutting edge to the material
25 consistent with changes in the direction of the motion of the
tool. A third winding 43 is set by the operator through a
potentiometer or other singal device 44 to control the
downward pressure exerted by piston 38 on knife 35. The
effect of this downward pressure will be hereinafter more
30 fully described with respect to Figure 5.

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1   As illustrated in Figure 2, the aluminum or titanium
workpiece 11 has been greatly exaggerated in depth relative to
the size of the tangential scribing tool to illustrate the
relationship between the depth of the feed stock 11a, and the
5 depth of the flow coat mask 12a. In actual practice, the
aluminum or titanium work stock 11a ranges in thickness as
illustrated by the arrows "A" from 1/8 of an inch to 1/2 an
inch in thickness. The thickness of the mask resist coating
12a, indicted by the arrows "B" in Figure 2 is approximately
10 10 mils. The reciprocal range of knife 35, indicated by the
arrows "C" in Figure 2 is approximately 1/8 of an inch. Thus,
it is apparent that even with two-dimensional flat stock, the
tangentially controlled scribing tool 14a is able to
compensate for any waves or variations in surface thickness of
15 the feed stock 11a as it scribes the surface.
        The feed stock 11a may be any metal that is suitable
for etching or other chemical milling. In the preferred
embodiment, it takes the place of aluminum, or one of its
alloys, or titanium, or one of its alloys, commonly used in
20 the aircraft and aerospace industry. One such aluminum alloy
is generally designated in the trade as 20-20-4 and meets a
federal specification entitled Q-A-250/4 or Q-A-250/5. One of
the titanium alloys used in the present invention is
designated in the trade as a 6-6-2 titanium alloy and meets a
25 military specification entitled T-9046. It includes, in
addition to titanium, 6 parts of aluminum, 6 parts of vanadium
and 2 parts of tin.
        These metals are etched in separate etching baths
although it is apparent from the prior art that a wide variety
30 of etching solutions could be used. In the preferred practice
of the present invention, the aluminum alloys are etched in a
sodium hydroxide alkaline bath while the titanium alloys are

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1 etched in a hydrofluoric acid bath. Other desired baths for
   aluminum may include caustic soda or potassium hydroxide, and
   another chemical bath that may be highly desirable for
   titanium is nitric/hydrofluoric acid.

5   While aluminum and its alloys, and titanium and its
   alloys, are the principle metals used in the present
   invention, it is apparent that any metal or material
   susceptible to etching by an oxidizing acid or strong alkali
   solution would be usable with the present invention.

10.   As illustrated in Figure 3, the workpiece 11a
   illustrated in Figure 2 has been immersed in an etching bath
   to remove a portion of the metal by chemical milling. The
   distance "D" representing the depth of the etchant cut varies
   widely depending on the material, the etchant bath, the

15 temperature and the period of time in which the material is
   immersed in the etchant. The parameters involved in the
   etching steps such as the concentration of active agent, the
   temperature, the etching rate, etc. will vary from application
   to application.

20   In the preferred embodiment, when aluminum and its
   alloys are etched in sodium hydroxide, from .0008 to .0022
   mils of material will be removed for each minute of immersion
   in the etchant bath. When titanium and its alloys are
   immersed in hydrofluoric acid, from .0006 - .0012 mils will be

25 removed for each minute in the hydrofluoric etchant bath. It
   should be noted that all of the workpiece 11a is protected by
   the masking material applied at step 12, except that portion
   which is desired to be chemically milled. Thus, the lower
   mask 12c protects the underside, or in the case of an aircraft

30 skin section, the outer side of the feed stock 11a.

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1   As illustrated in Figure 4, a workpiece 11b has been
subjected to a multiple etching bath. Multiple cuts were made
at 14b, 14c and 14d through the protective mask to define
separate masks 12a, 12b and 12c. After the cuts 14a-14d were
5 made, cuts 14c and 14d were resealed with "TURCO" or the
styrene/butadiene copolymer mask material as indicated at 30a
and 30b. The initial portion 12a was removed by hand as
illustrated in Figure 4, and the first layer of metal was
etched away as indicated by the dotted line surrounding 31a.
10 Following this initial etching, the sealant material 38a was
removed, the cut mask material indicated at 12d was removed,
and the workpiece was reinserted in the etchant bath. During
the second immersion, the metal indicated at 31b was removed
by action of the etchant bath.

15   After the desired amount of metal had been removed,
the third section of cut mask material 12e was removed, and
the portions of metal indicated at 31c were removed during the
third immersion in the etchant bath. Thus, it is apparent
that many possible various surface configurations could be
20 milled by virtue of the multiple etchant bath process
illustrated in Figure 4.

        The curve illustrated in Figure 5 illustrates the
depth of the cut by the knife blade 35 through the mask 12a and
into the metal substrate 11a. The horizontal axis labeled
25 "force settings" are indicative of the signals provided by
means 44 which originate from the scribe control 26
illustrated in Figure 1. While normally this is preset by the
operator at the time the cuts are made in the mask, the signal
could be supplied as part of the data processing signal stored
30 on magnetic tape 23. As indicated by the slope of curve 50
and 51, the pressure generated by the torque piston 38 and
winding 43 is sufficient to readily cut through the mask, but

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only lightly score the feed stock. As illustrated in Figure
5, the maximum depth of cut through the aluminum feed stock
was .002 inches even at the highest "force setting" for the
tangentially controlled scribing tool. This is well within
the .004 limit set by current military specifications.
Inasmuch as the titanium feed stock is substantially harder
than the aluminum feed stock, the depth of cut into the
titanium is even less than the cut into the aluminum.

The scribe control step illustrated at 26 in Figure
1 is more fully illustrated in Figure 6 in the form of scribe
control head 26a. The scribe control head 26a is mounted on a
Kongsberg Flatbed Drafting Table as illustrated in Figure 7.
This particular drafting table may be extended in 1-1/2 meter
sections up to a maximum length of 10.5 meters. The scribe
control 26a is carried by a gantry 50 for movements along the
x axis and by carriage means 51 and 52 which reciprocate along
guide rails 53 and 54 (not shown) mounted on either side of
the flatbed drafting table. A pair of high performance dc
servo motors provide for precise x,y positioning of the scribe
control 26a by means of rack and pinion drive mechanisms. The
pinions for carriage 51 and 52 are connected via a single
shaft and engage racks mounted in the guide rails 53 and 54 for
reciprocation along the y axis of the table. A single pinion
in the scribe control 26a reciprocates the scribe control
along a rack mounted in the gantry 50. The surface flatness
of the bed is plus or minus 0.75 millimeters, or well within
the 1/8 vertical reciprocating dimension c indicated in
Figure 2. The cutting speed of the table can be as high as 42
meters per minute.

1   The scribe control 26a illustrated in Figure 6 has the tangentially controlled scribing tool 14a and a pair of marking pens 55 and 56, one of which is cut away from the purposes of illustration in Figure 6. The scribe control 26a

5   also contains a resealing means 30a that is connected to a reservoir of maskant material such as TURCO, or any sealant that is compatible with the maskant material and capable of withstanding the acid or caustic bath to which the mask material will be subjected during the multiple etching steps.

10   The resealing step 30 is carried out be means 30a by means of a rolling ball 58, a brush, or other fluid dispenser as may be desired, depending upon the flow characteristics of material to be dispensed therefrom. In some applications of the invention, it may be desirable to combine the sealant with an

15   ink or other contrasting pigment to provide a single step that marks and reseals the cut scribe line. A plurality of air pressurizing means 59, 60 and 61 pressurize the containers of sealant 57 and ink containers (not shown). The inks are then dispensed to marking pens 55 and 56 by means of tubes 62 and

20   63 for marking the cut lines after the tangentially controlled cutting tool 14a has cut through the mask.

    Electronic control for the scribing tool is maintained through an overhead cable 64 illustrated in Figure 7 to the scribe control 26a. Electronic control of each of

25   the cutting, marking and resealing stages is provided by means of connector 65 and control line 66. The air supply for the tangentially controlled cutting tools air bearing is provided through conduit 67 while conduit 68 provides a similar supply for the ball applicator means 30a used in resealing the cut

30   scribe lines.

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1   While the Kongsberg Flatbed Drafting Table
illustrated in Figure 7 is capable of a relatively high rate
of movement in the x and y axes, it normally does so only on
straight cuts. The software provided for the Kongsberg table
5 at 28 in Figure 1 provides the CPU 25 with a "look ahead"
feature that enables the CPU to look ahead at the next block
of instructions and slow the scribing tool 26a when a change
in direction is indicated. For example, if the device is in
the mask cutting mode, with the tangentially controlled
10 scribing tool cutting through the mask cut material 12a, any
change in angle for the knife blade 35 of more than 7° results
in a vertical reciprocation of the piston 38 illustrated in
Figure 2. The movement of the scribing tool 26a is
momentarily halted, the blade 35 is raised and repositioned
15 with respect to its new angular orientation by means of signal
generators 41 and 42 provided by the scribe control 26. It
should be noted that the instructions from the CPU 25 to the
Kongsberg table 28 to the scribe control 26 are in analog
form insofar as the tangentially controlled scribing tool is
20 concerned.
    The reciprocal cutting feature of this device
enables the operator of the device to insert a very narrow
knife point for blade 35 and to cut holes in the mask material
of very small diameter. A round circular hole as small as 1/4
25 of an inch in diameter may be smoothly cut in the mask
material with the present invention. Cuts of this size radius
have been heretofore impossible with a handcutting operation.
In addition to making cuts that were previously impossible,
the present invention makes possible high speed scribing with
30 high precision and repeatability. As indicated previously,
one workpiece three-feet by four-feet with multiple parts that
took 6 to 8 hours to handscribe and mark by hand took 11
minutes to scribe and mark with the present invention.

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1   The present invention also makes possible the
application of the scribe control 26a to three-dimensional
workpieces as illustrated in Figures 8-10. The scribe control
26a is mounted on a robotic device 60 for cutting, marking and
5 masking the interior of a workpiece as illustrated in Figure
8. The master mold 70 has thereon a workpiece 11f that has
been preshaped to a three-dimensional contour.

      The workpiece 11f has also been coated with coating
12a and is ready for cutting, marking and resealing as was
10 previously described with respect to Figures 2-4.

      The robotic device 60 is equipped with a plurality
of rotational axes, each of which assists the device in
transporting the scribe control 26a from one point on the
x,y,z axes to a second point on the x,y,z axes. The pedestal
15 71 rotates about a pedestal turning moment 72 which is
described as $\emptyset$. The second robotic motion is the in and out
moment of the lower arm 72 and is described by the angle θ.
The third rotational axes prescribes the up and down motion of
arm 73 about the angle δ. The robot may also be equipped with
20 three separate motions for the wrist, although only two are
illustrated in Figure 8. The first wrist moment is α which is
referred to as a "wrist bend," and a second rotational axis β
which is indicated as a wrist turn. These five rotational
axes make it possible for the robot to traverse from any x,y,z
25 coordinate point to the next x,y,z coordinate point. As was
indicated previously with respect to Figure 1, each of the
servo motors responsible for moving the robot about each of
the five axes illustrated in Figure 8 may be programmed to run
simultaneously so that all axes start at the same time and run
30 at the same motor speed. Each motor then stops when the part
it drives has reached its new programmed position.
Alternately, the robotic device manufactured by "ASEA" has in

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1 instruction function that will provide a motor speed for each
   axes to be selected so that all axes reach the new programmed
   position simultaneously. This provides for smooth contouring
   of three-dimensional work surfaces when the robot is

5 traversing a curve through three-dimensional space. Also, as
   was indicated previously, the tangentially controlled scribing
   tool exerts a constant downward pressure on the scribing knife
   throughout a reciprocal range of 1/8 of an inch. This
   reciprocal movement of the knife provides that the knife

10 remains in a constant force engagement with the aluminum or
   titanium workpiece throughout the various movements of the
   robot's arms. The robot has a positional tolerance for all
   five axes of ±.004 mm which.is compensated for by the air
   bearing reciprocal tolerance of 1/8 of an inch as indicated at

15 "C" in Figure 2.

          Figure 9 illustrates the traditional x,y,z axes
   normally used to span three-dimensional space. A fourth axis
   is illustrated to note that any set of x,y,z axes could be
   used, provided that no two axes are parallel to one another.

20 If a particular set of x,y,z axes is more efficient in
   calculating the movement through three-dimensional space with
   respect to a given surface part configuration, then the x,y,z
   axes for that particular part may be altered to provide for
   more efficient calculation of the movements from one x,y,z

25 point coordinate value to another.

          Figure 10 is an illustration of a part of an
   aircraft that has been chemically milled after the mask was
   cut by a robotic device as illustrated in Figure 8. As
   indicated, the aircraft skin 81 remains coated with the resist

30 material on its lower surface throughout the entire milling
   operation. The ribs 82, 83 and 84 and stringers 85, 86, 87
   and 88 are integrally formed with the skin 81 to provide a

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1 unitary structure that is lightweight, strong and free from
   any mechanical joints, rivets, screws or other fastening
   devices. The natural undercutting action of the chemical
   milling process will provide a natural "T" or "I-beam"
5 configuration for strengthening the metal skin 81.

           Figure 11 illustrates one further advantage of the
   present invention. The metal part 11g has defined thereon a
   template outline that has been cut and marked along 14a, 29a
   as illustrated in Figure 1. A pair of tooling holes 90 and 91
10 have been defined within the chemically milled areas for
   gripping the part as it traverses through the various
   manufacturing steps that it will encounter. The part 11g is
   covered with a mask material 12a outside the perimeter line
   defined by 14a, 29a. The perimeter line 14a, 29a defined on
15 part 11g is typical of a part configuration that might be
   formed. An optional method for providing tooling holes is
   illustrated in the phantom lines for part 11h and tooling
   holes 92 and 93. This type of registration or tooling hole
   configuration might be utilized if it were desired to have a
20 part configuration having no holes therein which was
   chemically milled to reduced thickness. After completion of
   the chemical milling and de-smutting operation, the tab
   portion 11h would be cut along the outer perimeter line 94 by
   a router or metal saw in the part separation process.

25   As hereinbefore described, the present invention
   eliminates tedious handscribing of the mask on flat and
   three-dimensional parts intended for chemical milling. It may
   eliminate the construction of new templates for new parts that
   are to be manufactured and will eliminate the use of existing
30 templates for parts that have already been designed. . It
   eliminates the handmarking of multiple scribed areas and cuts
   and eliminates the hand application of TURCO sealer on the

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1   cuts to be used in sequential etching of the part. It
    provides a controlled depth of cut through the mask into the
    metal part that is very precise. The cutting can be conducted
    at high speeds with high precision and high repeatability.
5   The tangentially controlled scribing tool makes it possible to
    cut curves on both flat and three-dimensional surfaces and to
    define holes and curves that have not heretofore been
    previously possible with handscribed operations.

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WHAT IS CLAIMED IS:

1. An automated chemical milling process for metals, said process comprising the steps of:

   (a)   coating 12 the metal to be etched with a resist coating;

   (b)   digitizing 17 the area(s) to be etched to define at least x and y coordinate values for the perimeter of the area(s) to be etched;

   (c)   automatically scribing 25,26 the metal and coating with a scribing tool 14, said scribing tool cutting through said coating along the perimeter defined by the x and y coordinate values;

   (d)   removing 32 the resist coating from the area(s) to be etched; and

   (e)   immersing said partially coated metal into an etching solution 31 for a predetermined period of time to remove a predetermined amount of metal from the uncoated area(s).

2. An automated chemical milling process for metals, said process further comprising the steps of:

   (a)   defining a three-dimensional space with three separate x, y and z axes; wherein no two axes are parallel to one another;

   (b)   digitizing 17 the area(s) to be etched with x, y and z point coordinate values; and

   (c)   scribing 26,27 the coating and metal along one or more three-dimensional perimeter(s) defined by said x, y and z point coordinate values.

3. An automated chemical milling process for three-dimensional metal parts as claimed in Claim 2, which further includes the steps of defining three or more rotational axes 26a for the scribing tool, said scribing tool selecting one or more of said rotational axes as it traverses said three-dimensional space defined by said x,y,z coordinate values.

4. An automated chemical milling process as
claimed in Claim 1 or 2 or 3 which further includes the steps
of:

(a) separately scribing 14b,14c,14d more than one
area to be etched for each metal part;

(b) recoating the cut scribed lines 30a,30b for all
but one of the areas to be etched;

(c) sequentially removing 12a the resist coating
from each of the areas to be etched between separate
additional immersions in said etching solution;

whereby each of the defined areas to be etched is
immersed in said solution for differing cumulative time
periods.

5. An automated chemical milling process for
metals as claimed in Claims 1 or 2 or 3, which further
includes the step of marking the perimeter(s) of the area(s)
cut by said scribing tool with a visible marker, said marker
marking said coating along the perimeter line(s) defined by the
x,y coordinate values, said marking occurring before said
resist coating is removed.

6. An automated chemical milling process for
metals as claimed in Claim 4, wherein the recoating step
utilizes a visible sealant to simultaneously reseal and mark
the cut scribe lines.

7. An automated chemical milling process for
metals as claimed in Claims 1 to 5, which further includes the
step of nesting 12a,12d,12e,12b the perimeter lines of each of
the areas to be etched when more than one part is to be etched
from a single metal plate.

8. An automated chemical milling process for
metals as claimed in Claims 1 to 6, which further includes
the step of applying a predetermined constant force on the
scribing tool 35 to force said scribing tool into engagement

with said metal part 11a, said force being applied perpendicularly to a plane defined by at least two point values for each point traversed by said scribing tool.

9. An automated chemical milling process for metals as claimed in Claims 1 to 8, which further includes the scribing and etching of registration marks 90,91 in a metal plate.

10. An automated chemical milling process for metals as claimed in Claim 9, wherein tooling holes 90,91 are subsequently formed from said registration marks.

11. An automated chemical milling process for metals as claimed in Claims 1 to 6, which further includes the step of raising the scribing tool whenever a line or curve described by a future set of point coordinate values varies from a line or curve scribed from a previous set of point coordinate values by more than 7°.

12. An automated chemical milling process for metals as claimed in Claims 1 to 11, in which the metal 11 is aluminum or its alloys, and the etching bath 31 is an alkali metal hydroxide.

13. An automated chemical milling process for metals as claimed in Claims 1 to 11, in which the metal 11 is titanium or its alloys, and the etching bath 31 is a hydrohalic acid.

14. An automated chemical milling process for metals as claimed in Claims 1 to 13, wherein said resist coating is a butadiene/styrene copolymer.
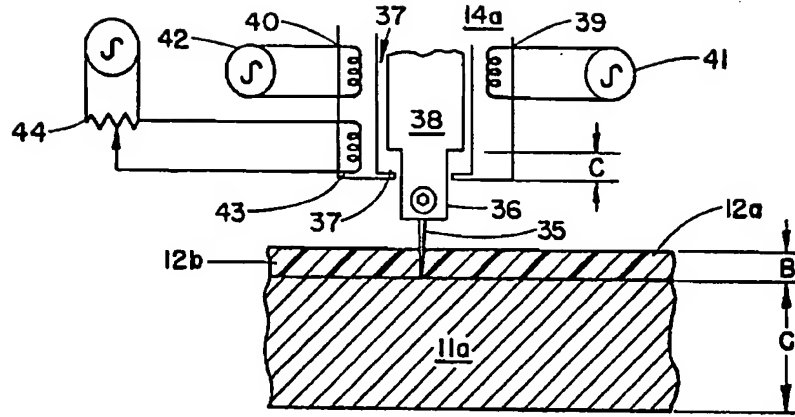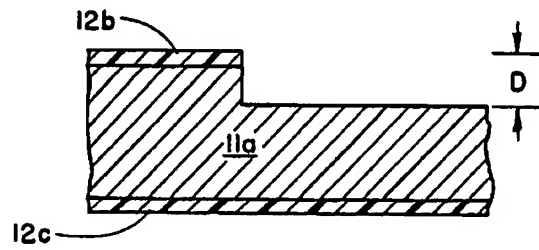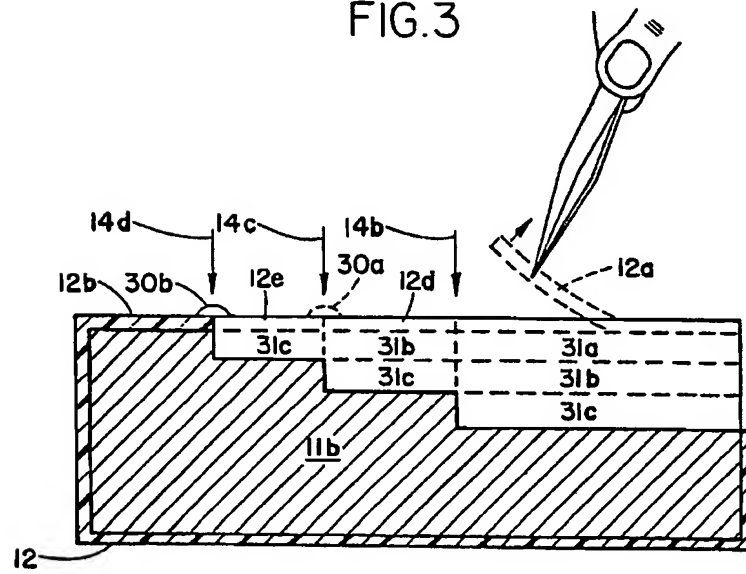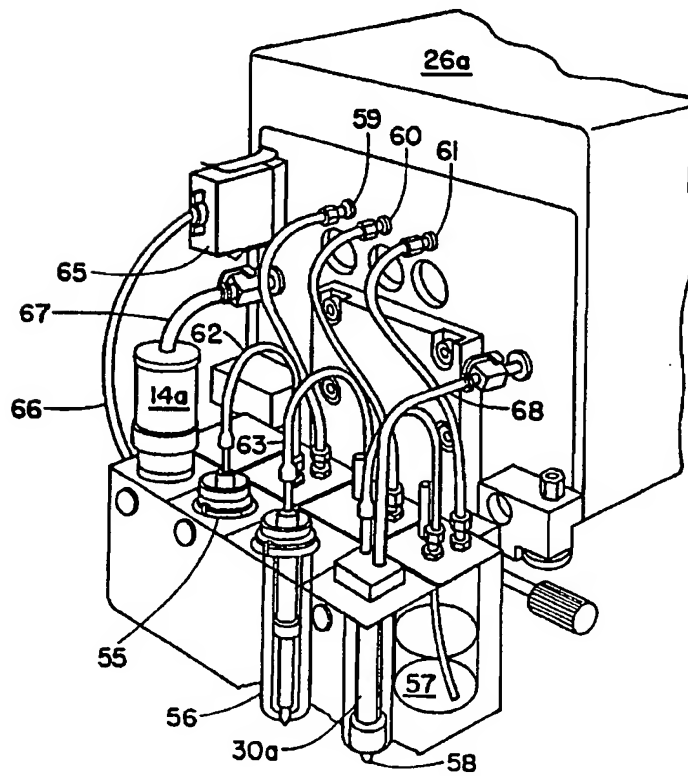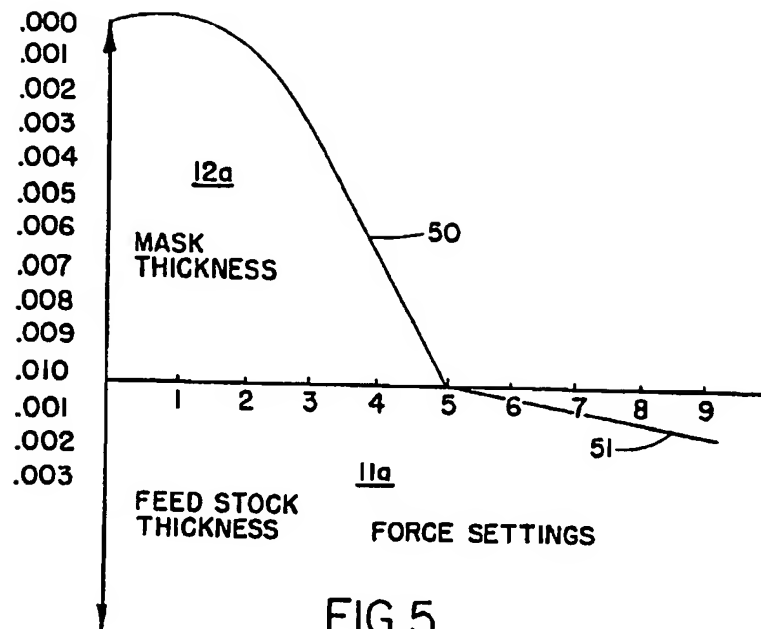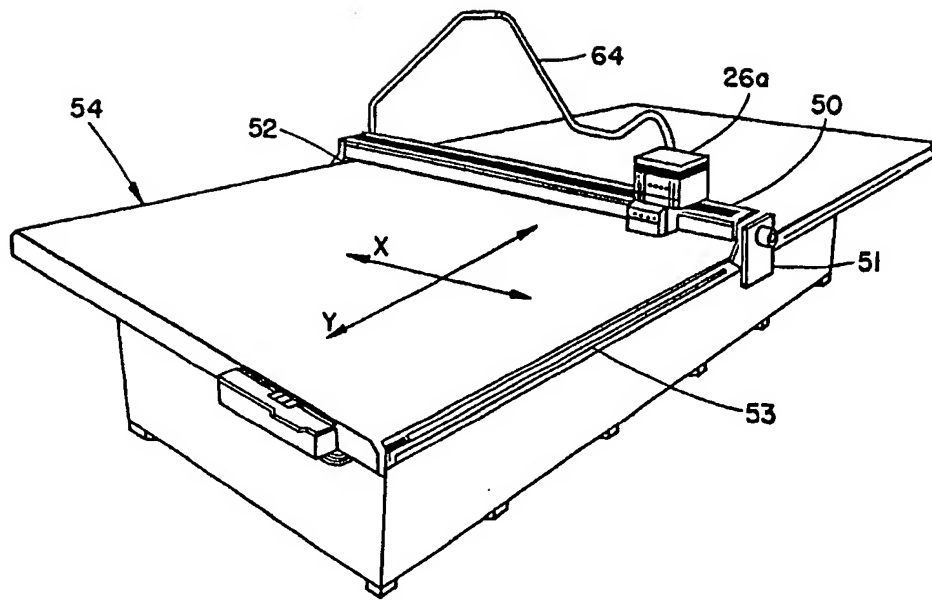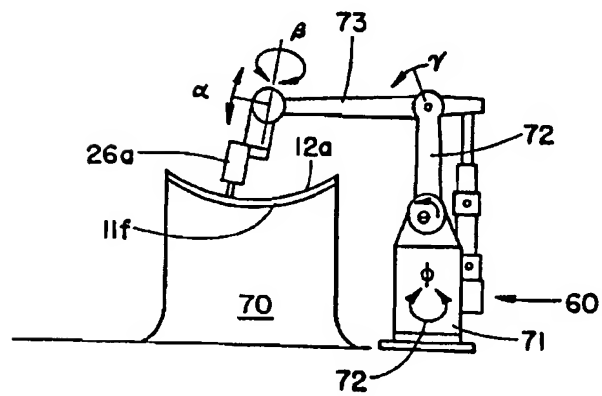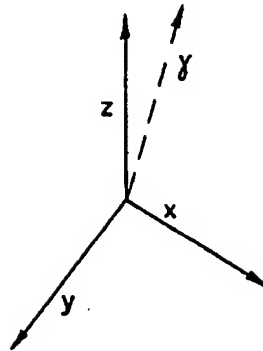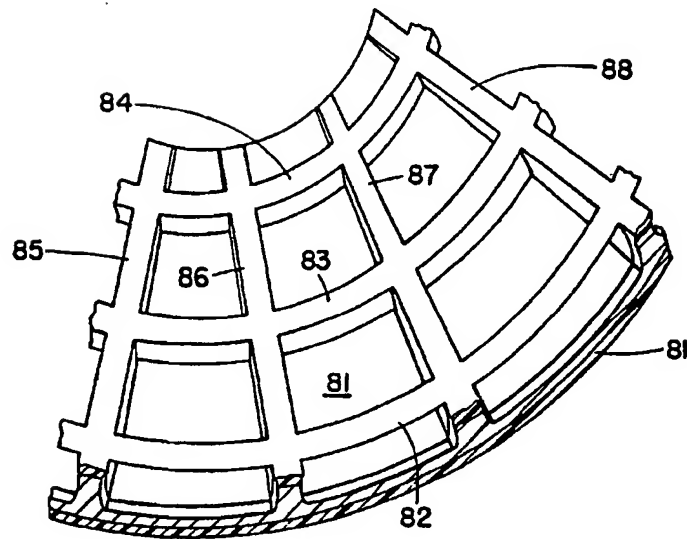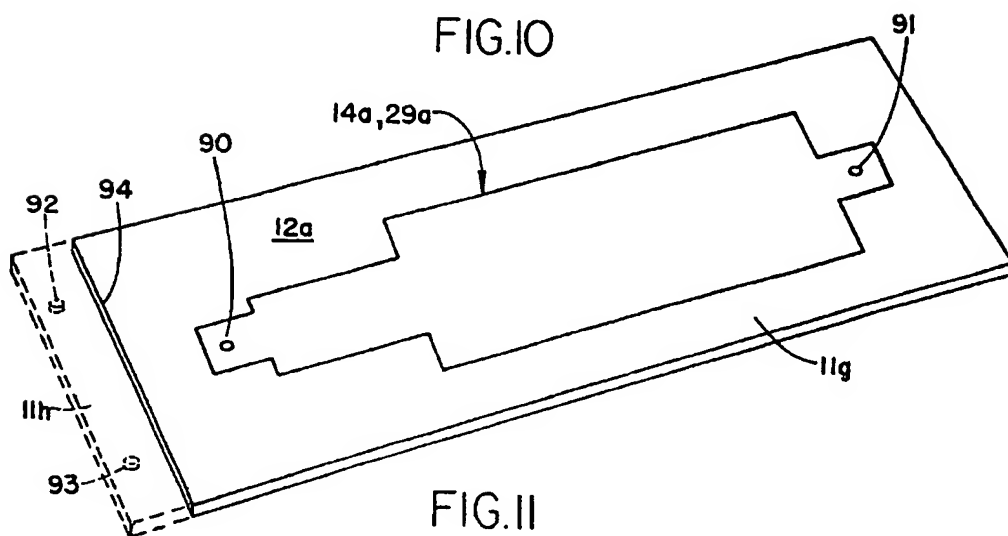
FIG.2

FIG.3

FIG.4

FIG.5

FIG.6

0179940

FIG.7

FIG.8

FIG.9

FIG.IO

FIG.II

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	US-A-4 137 118 (BRIMM) * Whole document *	1-5	C 23 F 1/04 G 05 B 19/405 G 05 B 19/19
Y	US-A-3 803 960 (PEARL) * Whole document *	1-5	
Y	US-A-4 117 751 (INOUE) * Whole document *	1-5	
A	EP-A-0 122 941 (FANUC)		
A	US-A-4 120 583 (HYATT)		
A	US-A-4 364 110 (HYATT)		
A	US-A-4 370 720 (HYATT)		TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	US-A-4 371 923 (HYATT)		G 05 B 19 C 23 F 1 G 06 F 15 B 23 Q 35
A	US-A-4 340 166 (BILANE)		
A	US-A-3 881 379 (STUMPF)		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	08-07-1985	RESSENAAR J.P.